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U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Measurement Laboratory
Office of Physical Measurement Services
Washington, DC 20234

March 1984

Prepared for
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National Bureau of Standards
Washington, DC 20234

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NATIONAL BUREAU OF STANDARDS RESPONSE TO THE 1982 NATIONAL MEASUREMENT REQUIREMENTS SURVEY OF THE NCSL NATIONAL MEASUREMENT REQUIREMENTS COMMITTEE

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National Bureau of Standards
National Measurement Laboratory
Office of Physical Measurement Services
Washington, DC 20234

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

NATIONAL BUREAU OF STANDARDS RESPONSE

TO THE

1982 NATIONAL MEASUREMENT REQUIREMENTS SURVEY

OF THE

NATIONAL MEASUREMENT REQUIREMENTS COMMITTEE

NATIONAL CONFERENCE OF STANDARDS LABORATORIES

Edited by:

B. C. Belanger
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NBS RESPONSE TO THE
1982 NCSL NATIONAL MEASUREMENT REQUIREMENTS SURVEY

INTRODUCTION

This report constitutes the response of the National Bureau of Standards (NBS) to the 1982 National Measurement Requirements Survey Report published by the NCSL's National Measurement Requirements Committee in May 1983.

Information of the kind contained in the Survey Report is extremely useful to NBS in evaluating the effectiveness of ongoing programs and for planning future programs. The Report is particularly important to NBS because of the large number of organizations that have responded and because of the detailed technical requirements identified in the report--quantities to be measured, ranges, and accuracies. NBS is grateful to the National Measurement Requirements Committee (NMRC) of NCSL for their extensive effort in collecting, summarizing, and tabulating the material and to the NCSL members (and non-members) who took the time to respond to the questionnaires.

The NCSL NMRC Report represents primarily the viewpoint of the standards laboratory community. NBS and the NMRC recognize that there are other users of NBS measurement services whose requirements may not be communicated to the standards laboratories that participated in this survey. For example, the views of many users of NBS ionizing radiation measurement services in the medical and health field are not well represented. Also, requirements from classified military programs cannot be included for obvious reasons. In spite of these constraints, NBS believes that the NCSL NMRC Report is one of the most comprehensive sources of technical requirements information for measurement services currently available.

The Report could have been even more useful had it contained more economic analysis and data that would permit NBS to evaluate the relative importance of the requested measurements to industrial productivity and quality control. NBS recognizes the difficulty of developing quantitative economic data and anecdotal material and encourages continued efforts to collect such data. In addition, in the continuing effort of NCSL to keep NBS aware of measurement requirements an attempt should be made to provide a prioritized list from each of the NMRC subcommittees that is ordered according to their perceived need.

The needs for expanded NBS services will probably always exceed the resources available to NBS for responding to those needs. Accordingly, NBS must set priorities carefully to ensure that resources are allocated to those measurement areas that are currently most important to the country. Since needs change as technology changes, some services will be closed while other new services are started. Because of the long lead times that are typically required to develop new calibration services and the high cost of research and development in new measurement areas, decisions to develop new services cannot be made without careful justification. The National Measurement Requirements Survey Report provides critically important information for project justification and priority decisions.

The subcommittees involved in the preparation of the Survey Report generally worked closely with the corresponding technical groups responsible

for NBS calibration services. In some cases information concerning the current status of NBS services and future plans was incorporated directly into the Survey Report. In such cases, this document includes only material deemed necessary to clarify or expand on the information in the NMRC Report or to cover those requirements for which NBS' current status and plans were not addressed. The format for the presentation of the material in the NMRC Report also varies from section to section. Each section in this report is labeled to correspond with the relevant section in the NMRC Report.

Some respondents to the NCSL questionnaire indicated that they were not aware of existing NBS services. NBS Special Publication 250, "Calibration and Related Measurement Services of the National Bureau of Standards" describes NBS' services and is updated every two years. The next edition of SP 250 will be issued in late 1984. An Appendix to SP 250 giving current prices and recent changes in services is published every 6 months. These publications are provided to anyone interested in using NBS services. Persons not already on the mailing list who wish to receive these publications should contact:

Office of Physical Measurement Services
Physics Bldg., Room B362
National Bureau of Standards
Washington, DC 20234
(301) 921-2805

For certain types of measurements, NBS Standard Reference Materials are a more convenient method of obtaining traceability to NBS. For information on Standard Reference Materials contact:

Office of Standard Reference Materials
Chemistry Bldg., Room B311
National Bureau of Standards
Washington, DC 20234
(301) 921-2045

In some cases, services that are not listed explicitly in SP 250 can be performed by NBS on a special test basis. Before concluding that NBS does not provide a particular service, the Office of Physical Measurement Services or appropriate NBS line managers should be contacted to see whether or not a special test can be arranged.

RESPONSE TO SECTION 2B
DC AND LOW FREQUENCY MEASUREMENT REQUIREMENTS

INTRODUCTION

The responsibility for providing calibration services and for carrying out research and development in dc/lf electrical measurements falls within two different Centers at NBS. The Electricity Division of the Center for Basic Standards (CBS) is responsible for dc voltage, impedance, ac-dc difference and resistance, whereas the Electrosystems Division of the Center for Electronics and Electrical Engineering (CEEE) is responsible for phase angle, power and energy measurements, and high voltage measurements.

Since the termination of the magnetic calibration services at NBS several years ago, no NBS group has carried out work in this area directed towards calibration services. The CEEE, however, has been surveying the field to determine whether there is sufficient justification for establishing a new magnetic measurements program at NBS. The Electricity Division also has expertise in magnetic measurements and is following this survey with interest. If the survey results and other considerations support a decision to reestablish magnetic measurement services, NBS will be in a position to draw on expertise in both centers (see Section on Magnetic Field Strength below).

The NCSL NMRC Report describes the general state of affairs in the metrology community and the needs expressed in it represent a wide range of opportunities for future NBS activity. In some cases, however, the accuracy requirements indicated in the NCSL Report are more stringent than those identified to NBS previously; e.g., the requirement for phase angle uncertainty in the NCSL Report is ±0.001 degree, other inputs had indicated an uncertainty requirement no better than ±0.005 degree. Also, NBS has received requests for dc/lf measurement services through other channels in addition to those indicated by the respondents to the NCSL Survey.

GENERAL COMMENTS ON NBS PRIORITIES AND PLANS

NBS Contact: Norman B. Belecki (301) 921-2715

The highest priorities in this area are to continue to maintain services related to fundamental standards with the highest level of quality; to reduce turnaround time in those services where there is room for improvement; to reinstate previously curtailed services in the resistance area; and to document the technology and procedures used to deliver existing services. The second priorities are to expand existing services and to initiate new services as indicated in this study and by the various members of the metrology community. These include:

a) Developing a calibration capability for capacitance dissipation factor;

b) Extending the ranges of measurement and applied frequency for the impedance calibration services;

c) Providing a calibration service for ac resistors at frequencies up to 100 kHz;

d) Developing a MAP procedure for alternating voltage and current measurements; and

e) Developing a MAP for dc voltage sources at the 10V level.

At present resource levels, services in these latter areas will not be available for several years.

NBS has increased the staff in this dc/lf area by two professionals and one technician. The first assignment of the professionals will be to automate the calibration of thermal current and voltage converters. This effort is expected to reduce the backlog of work in this key area and to allow some improvement in our measurement uncertainties. The second assignment of the professionals will be in the impedance area.

The new technician should allow the restoration of services for odd-decade value resistance standards. Calibration of resistors at the teraohm level and higher is also expected to be resumed when an automated capacitive discharge system for making the measurements is completed. Several publications covering measurement techniques in the voltage and resistance areas will be prepared.

NBS also assigns a high priority to maintaining reference standards and providing calibration services for electrical power, energy, and phase angle. In the Power/Energy area, existing services will be upgraded by increasing the accuracy and the range of quantities that are currently measured. The calibration service for phase angle, now provided on a special test basis up to 5 kHz, is expected to become a regularly-offered calibration service for frequencies up to 50 kHz. Work is underway with existing funding to accomplish this upgrade. These plans will permit NBS to address the principal needs indicated in the NCSL survey in a time span of about 3-5 years. Without additional funding, however, all of the needs indicated in the NCSL survey cannot be fully met; e.g., phase angle uncertainty within ±0.001 degree. As our plans are responsive to the needs of the users, no major modifications of these plans are necessary, only the funding to carry them out in a timely fashion.

DC VOLTAGE MEASUREMENT

NBS Contact: Norman B. Belecki (301) 921-2715

The requirements, current status, and future NBS plans were covered in the NCSL Report but are repeated here for convenience of the reader.

Requirement	Current NBS Capability	Plans and Comments
1. 10 volt MAP and calibration service with an uncertainty in the order of 0.1 to 0.3 ppm.	A calibration service based on an automated measurement system is now available with 0.3 to 0.5 ppm accuracies.	Work on the development of improved transport standards will be completed in 1 to 2 years.
2. 0.01 to 1000 volt MAP or calibration service having an uncertainty of about 1 to 10 ppm.	None.	The NBS ratio capability would need to be rejuvenated and transport standards and procedures developed. No plans have been made at this time.
3. 1 volt MAP with an uncertainty of 0.1 to 0.2 ppm. Turnaround time must be reduced to four weeks.	Two MAPs are available at different accuracy levels. The highest accuracy is at the 0.3 to 0.5 ppm.	New transport standards are being developed but will not be available for several years. Turnaround time has been reduced to five weeks which is the best we can do at this time.

AC/LF VOLTAGE MEASUREMENT

NBS Contact: Norman B. Belecki (301) 921-2715

The requirements, current status, and future NBS plans were covered in the NCSL Report but are repeated here for the convenience of the reader. The reader is also directed to the voltage measurement requirement in Section 2C.

Requirement	Current NBS Capability	Plans and Comments
1. AC voltage calibration service in the range 0.1 to 100 V: 20 Hz to 20 kHz; ±5 ppm 20 to 100 kHz; ±10 ppm 100 kHz to 1 MHz; ±100 ppm 1 to 50 MHz; ±200 ppm	AC-DC difference calibrations tions are available as indicated: 0.1 to 1000 V 2 to 20 Hz; ±200 ppm 20 Hz to 20 kHz; ±50 ppm 20 to 50 kHz; ±70 ppm 50 to 100 kHz; ±100 ppm 0.1 to 0.5 MHz; ±200 ppm 0.5 to 1 MHz; ±300 ppm	Two new staff members will work toward the automation of the test equipment. Planned completion in 1985.
2. AC voltage transfer standard	None.	Solid-state thermoelements are being investigated as the basis for a voltage transfer standard.
3. AC Voltage MAP	None.	No plans have been made at this time but the development of such a MAP for voltage measurement must consider the use of either sources or measurement systems as the transfer standard.

NBS Contact: Barry A. Bell (301) 921-2727

In addition, it should be noted that work is underway in the Electrosystems Division to develop two automated systems. One system is capable of calibrating alternating voltage sources or voltmeters in the ±10 ppm accuracy range, 1 to 1000 V, up to 100 kHz. This system can also characterize the ac-dc difference of thermal voltage converters. A second more portable system is being developed for calibrating dc/ac voltmeters in the ±5/±50 ppm accuracy range which may ultimately cover frequencies up to 1 MHz. The primary application is calibration of programmable sources and automated test equipment. This work is jointly funded by NBS and the Calibration Coordination Group of the Department of Defense.

DC AND AC RESISTANCE MEASUREMENT

NBS Contact: Norman B. Belecki (301) 921-2715

Requirement	Current NBS Capability	Plans and Comments
1. Calibration of ac resistance standards over the range 0.1 to 100 kΩ at frequencies from 60 Hz to 10 MHz.	None.	There are no current plans to provide services for ac resistors above 1 Ω and frequencies above 10 kHz. The capacitance work must be completed first.
2. Calibration of multimegohm resistance standards up to 10 TΩ at 250 V.	Services are available for the range 1 MΩ to 1 TΩ at voltages between 1.5 and 500 V.	Services for the range above 1 TΩ were suspended several years ago. It is anticipated that these services will be reinstated upon completion and testing of a new automated measurement system. Planned completion in 1984.
3. Calibration of resistors for high current measurements with capacities of up to 2 kA at the 0.02% accuracy level.	Shunt calibrations are carried out twice yearly for resistors with capacities up to 1 kA at accuracies of 0.01%. Above 1 kA, values with 0.03% accuracy are arrived at by measurement at 1 kA but at the elevated temperatures expected from desired current levels.	There are no immediate plans to improve this capability. Requests for calibrations at higher currents have been referred to the National Research Council in Canada.
4. Calibration of ratio devices such as direct reading ratio sets.	Currently suspended	While ratio measurements are often difficult, ratios are, in principle, self-realizable by using bootstrap techniques. Thus, NBS has no plans to resume ratio device calibrations in the near future. However, such measurements are the keystone for resistance and voltage scaling, and future Voltage MAP work will require their improvement. Future seminars on ratio measurements will be considered.

CAPACITANCE MEASUREMENT

NBS Contact: Norman B. Belecki (301) 921-2715

Requirement	Current NBS Capability	Plans and Comments
1. Calibration of 2-, 3-, and 4-pair-terminal standard capacitors over the range 1 to 1000 pF at frequencies from 100 Hz to 10 MHz.	Services are available.	Future work will improve the accuracy to better than 10 ppm at the higher frequencies.
2. Measurement of the dissipation factor of standard capacitors.	None.	The future work mentioned above includes the capability of measuring the dissipation factor with an accuracy of better than 1 ppm.
3. Capacitance MAP services in the range 10 pF to 1 mF at frequencies from 1 kHz to 1 MHz.	Currently suspended.	This service will be resumed with new transport standards for 1 μF at frequencies from 400 Hz to 1 kHz. Future work will increase the frequency range.
4. Calibration of standard capacitors to 1 μF at frequencies of 120 and 1 kHz.	Service is available for capacitors up to 0.1 μF at frequencies up to 10 kHz.	There are no current plans to extend these services until the completion of 1. and 2. above.

NBS Contact: Robert E. Hebner, Jr. (301) 921-3121

5. Measurement of capacitance and dissipation factor of gas-dielectric and solid-dielectric capacitors at power frequencies and high voltage.	Services are available on a special test basis.	At frequencies from 50 to 400 Hz and at voltages above 50 V the accuracy is ±10 ppm for capacitance and ±5 ppm for the dissipation factor. There are no current plans to upgrade this capability.

MAGNETIC FIELD STRENGTH

NBS Contact: Frederick R. Fickett (303) 497-3785

The information presented in the Report regarding calibration needs in the area of magnetics is consistent with information we have gathered in a preliminary assessment of the field. Prior to the survey on magnetics service, NBS had identified a relatively small number of organizations in need of this type of magnetic calibration service. However, our investigation has shown that need for the service is likely to increase significantly in the near future as pointed out in the Report. This is due in large part to the increased use of nuclear magnetic resonance techniques in medicine and to the introduction into commerce of new magnetic materials such as soft amorphous magnetic alloys and the NdFe hard ferromagnets.

It should be pointed out that there are magnetic measurement areas not addressed by the NCSL survey, such as magnetic recording media and other computer-related fields, that are quite active and in which we have found a significant interest in standards and calibration.

The extent of the need and/or desire of industry and other government agencies for a magnetics service by NBS has been assessed in part by CEEE through numerous contacts with representatives of industry and of the industrial standards-setting organizations. Results are being analyzed from an extensive survey questionnaire mailed to about 2,000 individuals, including members of the IEEE Magnetics Society, ASTM Committee A-6 on Magnetic Properties, and the Magnetic Materials Producers Association. The results of this survey, in conjunction with other input and financial considerations, will determine the future direction of our magnetics work. NBS cannot operate a viable calibration facility unless it is based on a strong state-of-the-art research program in the field. Thus, our first priority is to determine if sufficient interest exists to support creation of a magnetics program which would involve basic research and development of magnetic metrology as well as the creation of additional Standard Reference Materials and, possibly, calibration services.

At the present time CEEE has a capability for making nearly all conventional magnetic measurements in the Electromagnetic Technology Division in Boulder. Operating equipment includes: fluxmeters and gaussmeters of various sorts that can measure flux densities from less than a microtesla to greater than ten tesla (field strengths from 0.8 to 8,000,000 A/m); vibrating sample, ac induction and cryogenic (SQUID) magnetometers for measurement of susceptibility and permeability over the temperature range from 4 K to room temperature; and superconducting and normal magnetic systems with fields to 9.5 MA/m. None of these systems are now configured or calibrated for true standards work.

The Electricity Division of CBS has the expertise and some of the required apparatus to carry out magnetic field strength calibrations with the highest possible accuracies achievable, especially at low field levels, but there is no plan at this time to reinstate a calibration service.

DC AND PULSE CURRENT MEASUREMENT
NBS Contact: Robert E. Hebner, Jr. (301) 921-3121

Current transformers in the power frequency range are calibrated by the Electrosystems Division on a routine basis. Calibration of ac shunts at power and audio frequencies is performed on a special-test basis in the range of 1 to 100 mΩ.

Funding has been obtained to develop a capability to evaluate shunts and current transformers used to measure welding currents. This application requires the measurement of current pulses with amplitudes up to 100 kA and durations of tens to hundreds of milliseconds. Development of a bridge for calibrating shunts down to 0.1 mΩ and up to frequencies of 100 kHz is progressing slowly with the present funding level.

Long range plans include support of dc current measurements from 5 to 2000 A as a step toward developing support for dc revenue metering in high voltage dc systems.

POWER AND ENERGY MEASUREMENT
NBS Contact: Robert E. Hebner, Jr. (301) 921-3121

NBS' present capabilities for power and energy calibration are restricted to power frequencies, 50 to 400 Hz, with a routine uncertainty of ±0.05%. Under special conditions, we are able to achieve uncertainties in the range ±0.01 to ±0.02%. These capabilities are for unity and 0.5 power factor, but no measurements at zero power factor and no VAR's.

At the present time we meet most (but not all) of the calibration requirements of our clients. Present plans are to gradually upgrade this facility during the next 5 years.

The goal is to develop a largely automated facility having the following characteristics:

Frequency	: 40 Hz to 10 kHz	Waveforms :	sinusoidal and distorted
Voltage	: 10 to 240 V	Quantities:	power, energy, VAR, power factor, voltage, and current
Current	: 10 mA to 10 A	Accuracy :	±0.01% to ±0.05% routine, ±50 ppm special
Power Factor:	all, zero to unity, positive and negative		

PHASE ANGLE MEASUREMENT
NBS Contact: Barry A. Bell (301) 921-2727

Phase angle calibration up to 5 kHz is presently provided on a trial basis as a special test. After experience is gained and documentation completed,

it is intended to offer this as a regular calibration service. R&D is underway on the higher frequency standard that will permit the extension of this service to 50 kHz. This high frequency capability (scheduled to be available on a trial basis by early 1986) is clearly important to support the calibration of Automated Test Equipment (ATE).

The capabilities that we are working toward are:

- Frequency: 10 Hz to 50 kHz
- Source-type standard (2 channel)
- Both channels voltages, balanced or unbalanced; or one channel voltage, the other current
- Sinusoidal signals and those with moderate distortion
- Accuracy: ±0.005 degree (best, at low frequencies, balanced signals), ±0.02 degree (at high frequencies)

OTHER DC AND LF MEASUREMENT AREAS

FIELDS

NBS Contact: Robert E. Hebner, Jr. (301) 921-3121

Special measurement services for electric and magnetic fields at dc and power frequencies are available as a result of work funded by the U.S. Department of Energy. These services should be particularly helpful to organizations involved in environmental and health-related investigations. For the measurement of relatively low field strengths, the strategy has been to maintain NBS traceability in the measurement of voltage and current (from which field strengths are derived), and to provide guidance in the construction of the test systems used to calibrate field meters. This approach is summarized in IEEE Standard 644-1979 "IEEE Recommended Practices for the Measurement of Electric and Magnetic Fields from AC Power Lines."

D/A AND A/D CONVERTERS

NBS Contact: Barry A. Bell (301) 921-2727

A calibration facility is available at NBS for high resolution data converters (12 bits and more). Calibration for static parameters is offered as an existing service; calibration for dynamic parameters is performed on a special test basis. The facility can also be adapted for calibrating certain parameters of DVM's (e.g., their linearity) but additional development funds are required for NBS to establish a regularly offered service.

RESPONSE TO SECTION 2C
RF AND MICROWAVE MEASUREMENT REQUIREMENTS

Section 2C of the NCSL Report contains a considerable amount of information concerning NBS' currently-offered services and our future plans. Accordingly, this section of this report does not attempt to duplicate that information. Rather, it elaborates on NBS' plans for the measurement requirements identified in the survey report and explains current constraints in more detail.

GENERAL RF AND MICROWAVE METROLOGY

NBS Contact: Cletus A. Hoer (303) 497-3705

The effort to develop and implement automated six-port measurement methods to the point that they can be used to provide NBS measurement services is nearing completion. New management for the Microwave Metrology Group is thus developing plans for the microwave metrology program for the next 5 years with a real opportunity to take up new work. In doing so, our chief sources of guidance are information from the NCSL Measurement Requirements Study, together with comments from our customers and sponsors and other interactions, for example information from the Workshop on Future Needs in Microwave Metrology that we organized at the 1983 IEEE-MTT Symposium in Boston. After some follow-up with the people who proposed new efforts, in order to set priorities, we will have an unusual opportunity to be responsive.

The tasks of immediate urgency are to complete the evaluation of uncertainty, provision for quality control, and the documentation of the 6-port systems and to bring them on line to replace obsolete calibration systems. We must also provide calibration services for attenuation at 1.25 MHz and for standards with 3.5 mm connectors. We need to complete the documentation of some of the older calibration systems that will remain in service.

Upon completion of these tasks, we will turn our attention to providing more complete calibration coverage of the frequency bands up to 100 GHz (especially filling the gap that presently exists between 40 and 55 GHz). The timing of requirements above 100 GHz remains nebulous, so our response to those may be given lower priority.

It is clear that calibration of microwave power is needed over a wider dynamic range and with greater accuracy that at present. We intend to respond to this need.

Finally, two general areas to which we will turn our attention are techniques for making measurements of microwave and millimeter-wave integrated circuits on-chip, and the calibration of automated test and measurement systems.

The dates for new services given under the plans and comments column are provided for guidance and are to be taken as our present best estimates of when services will become available. In some cases a service will be offered on an experimental basis at first, to test both the mechanics of providing it and customer response. Rough estimates of the cost of developing a service are provided for some services for which funding is uncertain to provide some feeling for the support required. Priorities can be shifted, or projects can be accelerated, if the need is great enough for other government agencies to provide additional funding.

POWER MEASUREMENTS

NBS Contact: Cletus A. Hoer (301) 497-3705

Requirement	Current NBS Capability	Plans and Comments
1. Measurement of power (0.1 to 200 W) from 10 MHz to 6 GHz with an uncertainty of ±1 to 10%.	None.	Service can be developed for $700K. Estimate service available end of 1987 for either 3-port couplers or bolometer-coupler combinations at power levels up to 200 W and frequencies to 1 GHz.
2. Measurement of high power (up to 25 kW) from 1 MHz to 2 GHz with an uncertainty of ±1.5%.	None.	Because of the high cost and very limited need, we have no plans to develop this service. However, high power, 60 dB directional couplers have been developed for 40 kW over the frequency range 1 to 30 MHz with uncertainties of ±1/2 to 1 dB. These couplers are described in NBS Report 9795, April 1971.
3. Measurement of low power (0.1 to 100 mW) in coaxial systems from 50 MHz to 26 GHz with uncertainties of ±2 to 5%.	Now provide service from 1 to 10 mW, 10 MHz to 18 GHz, ±0.5 to 1%.	Service at 10 mW from 10 MHz to 26.5 GHz available by end of 1985. Service below 10 mW will be developed by capability of measuring S-parameters of a 3-port coupler to be used as a power ratio device for power levels below 10 mW (down to 0.1 μW) over the frequency range 10 MHz to 26.5 GHz.
4. Measurement of low power (0.1 to 100 mW) in rectangular waveguide systems from 33 to 110 GHz with uncertainties of ±1 dB or ±5%.	Service available from 8 to 40 GHz and 55 to 110 GHz at selected frequencies. Frequency limited in WR15 and WR10 because of narrowband sources.	Service available in WR19 (40 to 55 GHz) at 10 mW by end of 1985. Extension of dynamic range by evaluating 3-port couplers having coupling ratios up to approximately 50 dB above and below 10 mW.

(table continued)

ATTENUATION MEASUREMENT
NBS Contact: Cletus A. Hoer (303) 497-3705

	Requirement	Current NBS Capability	Plans and Comments
5.	Measurement of attenuation in coaxial components from 0 to 70 dB, 0.1 to 26.5 GHz, with uncertainties of ±0.05 dB.	Now provide service from 0 to 50 dB, 0.1 to 18 GHz with uncertainties of ±0.03 dB/10 dB.	Plan to extend frequency range for 0 to 50 dB capability from 100 kHz to 26.5 GHz by end of 1985. Extend dynamic range to 80 dB by end of 1986 if other agency funding of $500K is available.
6.	Measurement of 6.0206 dB change of a voltage doubler at 1.25 MHz with an uncertainty of $\pm 4.7 \times 10^{-5}$ dB.	None.	We currently have a research project to measure the nominal 6 dB change in attenuation of a 2-position voltage doubler at 1.25 MHz with an uncertainty of ±0.0005 dB. Interim service will be available by 1984 but the uncertainty will be of the order of ±0.001 dB. If the project is completely successful, service will be available by 1985 with an uncertainty of ±0.0005 dB or better.
7.	Measurement of attenuation in rectangular waveguide components from 0 to 50 dB, 20 to 100 GHz, with uncertainties of ±0.05 to 0.5 dB.	Now provide service from 0 to 50 dB, 8 to 40 GHz, 55 to 65 GHz, and 94 to 96 GHz with uncertainties of ±0.05 dB/10 dB below 65 GHz and ±0.06 dB/10 dB from 94 to 96 GHz.	Provide service from 0 to 50 dB, and continuous frequency coverage from 18 to 110 GHz with uncertainties of ±0.005 to 0.1 dB. This will be done on one console based on 6-port techniques.

(table continued)

Requirement	Current NBS Capability	Plans and Comments
IMPEDANCE/ADMITTANCE MEASUREMENT NBS Contact: Cletus A. Hoer (303) 497-3705		
8. Measurement of capacitance (1 to 1000 pF) from 1 kHz to 10 MHz, with uncertainties from ±0.002 to to 0.5%.	Now provide service from 1 pF to 0.1 μF, 30 kHz to 250 MHz for two-terminal capacitors with nominal uncertainties of ±0.1%. Provide service for three-terminal capacitors from 0.01 to 1000 pF, at 100 kHz and 1 MHz with nominal uncertainties of ±0.02%.	No plans to provide 4-terminal calibration service, but Tech. Note 1024, "Evaluation of three-terminal and four-terminal pair capacitors at high frequencies," provides techniques to accomplish these measurements. No plans to measure dissipation factor at NBS/Boulder. See comments in Section 2B under capacitance measurements regarding plans for dissipation factor measurements at NBS/Gaithersburg.
9. Measurement of "Q" from 5 to 10,000, 10 kHz to 70 MHz with uncertainties of ±2 to 5%.	NBS can measure capacitive Q-standards from 1 to 10,000 at 1 MHz with uncertainties of ±2 to 20%. NBS can measure inductive Q-standards from 100 to 600 over the frequency range 50 kHz to 45 MHz with uncertainties from ±1 to 20%.	No plans to extend capability beyond what we now provide.
10. Measurement of four-terminal resistance to calibrate LCR meters.	None.	Research project in progress to determine how to evaluate these instruments. Measurement techniques describing how to evaluate four-terminal measurement instruments using two-terminal standards will be published by end of 1983.
11. Measurement of VSWR (1 to 1.5), 23 to 110 GHz, with uncertainties of ±0.002.	VSWR measured in terms of reflection coefficient. See item 7.	Capability will be provided by 6-port console described in item 7.

(table continued)

VOLTAGE MEASUREMENT
NBS Contact: Cletus A. Hoer (303) 497-3705
Normal B. Belecki (301) 921-2715

Requirement	Current NBS Capability	Plans and Comments
12. Measure voltage from 0.5 to to 20 V, 1 kHz to 100 MHz.	Capability exists.	NBS/Boulder will now calibrate at lower frequencies to uncertainties of ±0.05%. For better uncertainties, at or below 1 MHz, units must be calibrated at NBS/Gaithersburg.
13. Measure ac-dc difference in voltage of 1000 V from 20 Hz to 1 MHz with uncertainties from ±0.002 to 0.025%.	Capability exists except for requested uncertainties which range from ±0.005% over the frequency range 20 Hz to 20 kHz, ±0.01% over the frequency range 20 to 50 kHz, and ±0.05% over the frequency range 50 kHz to 1 MHz.	No plans to improve services. However, low frequency 6-port systems may improve uncertainties. Voltage measurements on 6-port system scheduled to be available at end of 1987.

PHASE SHIFT MEASUREMENT
NBS Contact: Cletus A. Hoer (303) 497-3705

14. VOR measurements of phase angle from 0 to 360° at a frequency of 9960 Hz to an accuracy of ±0.005°.	Capability exists.	Service now offered as a routine calibration service with uncertainties of ±0.0023°. The ILS service has been taken over by Aerospace Guidance and Metrology Center, Newark Air Force Station, Ohio.

MODULATION MEASUREMENT
NBS Contact: Cletus A. Hoer (303) 497-3705

15. Modulation measurements to calibrate HP 8901/11715A equipment.	None.	Very low priority for NBS funding. Would consider establishing service to calibrate modulation analyzers if funded by other agencies. Cost estimated in excess of $250K.

(table continued)

PHASE NOISE MEASUREMENT
NBS Contact: Cletus A. Hoer (303) 497-3705

Requirement	Current NBS Capability	Plans and Comments
16. Measurement of phase noise from 5 MHz to 300 GHz.	Capability exists.	Phase noise measurements can be measured by combining expertise from various NBS divisions as a special test. Routine calibration service would be prohibitively expensive for a very small workload. Suggest a joint NBS/industry meeting to resolve measurement problems in this area.

DIELECTRIC CONSTANT
NBS Contact: Charles K. S. Miller (303) 497-3131

17. Standard Reference Materials for dielectric constants at microwave frequencies.	None.	NBS has no plans for developing SRMs for dielectric constants at microwave frequencies.

FREQUENCY MEASUREMENT
NBS Contact: Roger Beehler (303) 497-3335

18. Frequency measurements from 75 to 110 GHz.	Capability exists.	NBS Time and Frequency Division can provide calibration of any frequency source.

PULSE TRANSITION DURATION MEASUREMENT
NBS Contact: Robert A. Lawton (303) 497-3339

A special test service is available for pulse transition duration, thus the requirement identified in this area is currently being met. Equipment is being updated to more effectively respond to customer needs. The precise capabilities that will be achieved await completion of this work.

Requirement	Current NBS Capability	Plans and Comments
Pulse transition duration 20 to 1000 ps; accuracy ±5 ps.	Pulse transition duration 10 ps to 1 μs; accuracy ±(0.5% ± 5 ps).	Updating in progress.

NOISE TEMPERATURE MEASUREMENT
NBS Contact: David F. Wait (303) 497-3610

NBS is looking to the recently developed automated total-power radiometer coupled with two noise standards, one at ambient and the other at cryogenic temperatures, to provide enhanced frequency coverage for reference noise temperature measurements. The automated radiometer system offers the potential of providing measurements at any frequency within ranges covered by a series of "front-end" sections and is intended eventually to replace earlier total power radio-meters, and sum-and-difference radiometers with both hot and cold noise standards, and the still earlier manually switched radiometers having only high-temperature noise standards. The new system is suitable for evaluating the new generation of solid-state noise sources and is now operational at 30 and 60 MHz and the nominal 94-GHz region. The range of 2 to 4 GHz is expected to be covered within about a year. With current levels of resources, NBS estimates that noise temperature measurement service based on the automated radiometer will be available over the range 500 MHz to 18 GHz in from seven to ten years. A service based on a total power radiometer is available in the range 55 to 65 GHz and we are currently seeking support from other government agencies to develop services with the automated radiometer in the nominal 20, 30, and 44 GHz regions.

The requirements for noise measurements at frequencies below 500 MHz identified in the NMRC Report exceed our current plans to provide service in that we anticipate providing spot frequency coverage, rather than broadband coverage, in this region. The reason is that broadband isolators having the required low insertion loss are not available. Should this situation change, the automated radiometer concept could in principle then be extended to lower frequency ranges to provide broadband coverage.

(table continued)

Requirement	Current NBS Capability	Plans and Comments
Noise temperature of solid-state noise sources; frequency range 10 MHz to 26.5 GHz; ENR from 5 to 20 dB; accuracy ±0.1 to ±0.3 dB; transmission lines, coaxial; connectors, type N, APC-7, APC-3.5.	Now provide 30 and 60 MHz and 3 frequencies in 2.6 to 3.95 GHz range. ENR and accuracy can be met. Limited connectors available in each frequency range; adapters from one size to another have not been completely evaluated; APC 3.5 not addressed as yet.	Within one year the service will cover 2 to 4 GHz. In the present WR-90 and WR-62 frequency ranges it is economically impractical to offer coax services. Coax connector adapter evaluation will be initiated in 1984; sliding shorts and loads for APC 3.5 need to be found. Current plans are to address 4 to 8 GHz in 1985 and 1 to 2 GHz in 1986. Other bands can only be addressed beyond this time frame.

FIELD STRENGTH MEASUREMENT

NBS Contact: Charles K. S. Miller (303) 497-3131

While the Report acknowledges the need for R&D to develop better emission and susceptibility testing methods for electromagnetic interference, the only requirements identified relate to more traditional antenna measurements for field strength of far fields. There are greater measurement challenges than these that need to be addressed, but standards laboratories traditionally are not involved with them.

NBS can respond to the requirements identified in the NMRC Report by means of measurement services in the "special test" category. At the same time, NBS is aware of other measurement needs in industry that are driven by ever-increasing EMI problems and that challenge the more traditional measurement approaches of the electromagnetic community. The NBS EMI program plans to develop measurement methods that are responsive to national and international specifications and regulations through the establishment of a metrology base to support reliable immunity and emission testing. Specifically, the program intends to address the requirements of the Federal Communications Commission (especially computer emissions) and the Food and Drug Administration.

(table continued)

Requirement	Current NBS Capability	Plans and Comments
Field strength to 40 dB above 1 μV/m; accuracy ±2 dB; frequency range: 30 to 1000 MHz; vertical polarization on open-field range.	Available as special test service.	None.
Field strength of 100 to 600 μA/m; accuracy ±3%; frequency range 150 to 200 kHz; TEM cell at 50 ohms.	Available as special test service.	None.

POWER DENSITY MEASUREMENT
NBS Contact: Charles K. S. Miller (303) 497-3131

The NMRC Report identifies requirements that are not new but are indicative of new concerns for occupational safety and health with respect to electromagnetic radiation. NBS expects power density measurements to become increasingly important as regulations are established and enforced by federal, state, and local governments. The NBS EMI program is developing the capability to respond to most of the identified requirements through measurement services in the "special test" category. These services are expected to start becoming available at the end of 1984.

The frequency range covered by plans in place for the NBS EMI program has an upper limit of 18 GHz. At least one NMRC respondent requests service at 26.5 GHz; it is unlikely that NBS will be able to meet this need for three to five years. In looking to the future of its EMI program, NBS recognizes that measurement services will be required at higher frequencies, to 100 GHz and even higher.

A specific need is for an improved radiation hazard monitor having a frequency capability above 10 GHz.

Requirement	Current NBS Capability	Plans and Comments
Power density range from 0.2 to 100 mW/cm^2. Frequency range from 0.3 to 26 GHz. Accuracy ±0.5 dB.	Range: 0.1 to 10 mW/cm^2 Frequency range from 0.3 to 2 GHz.	Instrumentation being installed will extend range to 18 GHz and power density levels greater than 100 mW/cm^2 with accuracy of better than ±1 dB by end of 1984. Error evaluation will not be complete until end that time.

RESPONSE TO SECTION 2D
ELECTRO-OPTICS MEASUREMENT REQUIREMENTS

The usefulness of the study is somewhat compromised by the small number of responses to the electro-optics portion of the survey. Dr. Richard Miller, Chairman of the Electro-Optics Subcommittee has indicated his plans for a program to reach the electro-optics community and provide additional input. When these additional data are available, the report should be very valuable to future planning for optical electronic metrology.

NBS recognizes that many of the needs in this technical area are classified or proprietary. In addition to the information presented in this NCSL Report, NBS does receive through other channels information that is used in establishing priorities. An important segment of the electro-optics community is represented by the Council on Optical Radiation Measurements (CORM). NBS works very closely with CORM, and CORM periodically publishes survey reports on measurement requirements. In Section 2D of the NCSL Report, the most recent CORM is summarized.

LASER AND OPTICAL FIBER MEASUREMENT

NBS Contact: Aaron A. Sanders (303) 497-5341

A number of measurement services currently exist for measuring the power/energy of laser beams. Measurement assurance programs have been developed for the more common types of lasers and other special calibrations can be accomplished for the common measurements not advertised in the NBS Special Publication 250 Appendix. Current calibration capability for lasers at 10.6 micrometers is about 500 watts. A transfer standard is being characterized and documented that will be available during calendar year 1984 for use to about 5 kilowatts (this transfer standard could also be characterized for 1.06 micrometer lasers). The BB calorimeter developed and constructed by NBS, which provides cw measurements to 200 kilowatts, was transferred to the Air Force some few years ago and is currently maintained by the Aerospace Guidance and Metrology Center, Newark Air Force Station, Ohio. They have agreed to provide measurements with this system. We are currently working on an absolute standard for use with lasers for the spectral interval of 400 nm to 15 micrometers working to pulse energy levels of about 15 picojoules. Measurements from this standard will be available during 1985. We currently have plans for developing laser beam profile standards and measurement services, but this program is contingent upon obtaining additional funding. A research program is presently being pursued to develop detectors and the electronic measurement apparatus for laser pulse measurements of about one picosecond. The implementation of measurement services around this standard is several years away. This time schedule could be compressed if additional funding became available.

	Requirement	Current NBS Capability	Plans and Comments
1.	Attenuation of optical fibers in the range of 0 to 50 dB with 0.1 dB accuracy.	Available	Special test program available for 1984 in the range of 0.6 to 40 dB.
2.	Laser power for welding; 0 to 400 watts at 1.06 μm (5%) and 2 to 5 kW (5 to 10%).	Limited	Transfer standard available during 1984 at 5% total uncertainty.
3.	Wedged beamsplitter (14 dB at ±1% and 59 dB at ±10%).	Available	Devices supplied to U.S. Air Force and Bureau of Radiological Health. Documentation available for customer to purchase from a commercial supplier.
4.	Ultra low level laser power (10 to 0.1 femtojoules at 1.06 μm)	Available	Transfer standards available for 1 femtojoule. Units supplied to Air Force and Navy for 0.1 femtojoule/cm^2.

(table continued)

Requirement	Current NBS Capability	Plans and Comments
5. Spectral characteristics of detectors, filters, and sources (0.25 to 2.0 μm).	Capability	A measurement service for spectral characteristics of detectors was available for 0.4 to 15 μm. It was never requested for the two years it was available. It could be offered again if there is sufficient interest. The Air Force was equipped to provide this service for DOD.
6. Seminar for laser power and beam diagnostics	Being Considered	NBS wll consider holding such a seminar during 1985.
7. Laser power (infrared, near term high energy laser calorimetry).	Available	NBS has developed calorimeters for high energy laser systems. We work closely with DOD and are not aware of requirements not addressed.

A special test measurement service will be available later this year for attenuation and bandwidth of multimode optical fibers. Arrangements can be made for special test services for core diameter, index profile, and numerical aperture. Research is currently underway for developing measurement methods for single mode fibers and fibers for optical sensors. Measurement services for these areas are as yet a few years away unless additional funding becomes available.

RADIOMETRY AND SPECTROPHOTOMETRY

NBS Contact: Donald McSparron (301) 921-3613

This section of the NCSL Report was structured to compliment and supplement the work of other groups addressing measurement needs in radiometry. Of particular note is the prior work of the Council on Optical Radiation Measurements (CORM). In preparing the NCSL Report, however, particular emphasis has been given to the needs of the aerospace community. This segment of the electro-optics community has not been completely represented in CORM. The NCSL Report thus forms a valuable addition to the information base utilized in planning future NBS activities in this area.

The measurement needs identified by the respondents to the NCSL survey and the NBS comments are presented in summary form in the following table. Because of the small number of responses to the NCSL survey, only part of the NBS program in radiometry and spectrophotometry is presented here.

RADIOMETRY

NBS Contact: Donald McSparron (301) 921-3613

Requirement	Current NBS Capability	Plans and Comments
1. Calibration of cryogenic blackbodies in the range 100 to 500 K with an uncertainty of 5%.	NBS now provides special test services in the range 200 to 400 K with an uncertainty of 5%.	Proposals to obtain DOD funding to upgrade the present capabilities are being actively pursued; progress is dependent on obtaining such funding.
2. Calibration of an ambient temperature blackbody in the range of 0 to 99 °C with an uncertainty of 0.02 °C.	NBS now provides special test services in the range -50 to 100 °C with an uncertainty of 0.05 °C (using a radiometer on loan from DOD).	An upgraded NBS blackbody with an uncertainty goal of 0.01 °C is being developed.
3. Calibration of radiant and spectral temperature of blackbodies in the range 232 to 1,000 °C with an uncertainty of 0.5 °C.	Inactive	NBS facilities have been inactive for 8 years due to lack of demand, calibration services are available from Newark Air Force Station.
4. Calibration of incandescent lamps for luminous intensity, tristimulus coordinates, and color temperature in the range 2,000 to 3,000 K with an uncertainty of 25 K.	NBS currently provides lamp standards in the range 2,000 to 3,000 K with an uncertainty with respect to NBS of about 10 K.	In accord with the recent redefinition of the photometric units, NBS is implementing a radiometric basis for the photometric scales. Reduced uncertainties are expected to be available in about 1 year.
5. Calibration of UV radiometers in the range 10 to 400 $\mu W/cm^2$, with uncertainties of 1 to 5%.	NBS now provides absolute spectral response calibration in the range 1 to 400 $\mu W/cm^2$, 250-500-960 nm with corresponding uncertainties of 5%-1%-1.5%.	Active research programs are attempting to extend the spectral and flux ranges available.
6. Seminar on photometry and radiometry fundamentals.	None.	None.

(table continued)

RADIOMETRY
NBS Contact: Donald McSparron (301) 921-3613

Requirement	Current NBS Capability	Plans and Comments
7. Calibration of an imaging infrared radiometer in the range 2 to 5 μm, 10^{-1} to 10^{5} Wm^{-2} sr^{-1} μm^{-1} with an uncertainty of 5 to 10%.	None.	Calibrations of blackbody sources suitable for performing such calibrations are available (see items 1, 2, and 3 above).
8. Spectral irradiance calibrations of deuterium lamps 200 to 350 nm and quartz halogen lamps 250 to 1600 nm.	NBS provides these calibrations on a routine basis with deuterium lamp uncertainties of 6% and quartz halogen lamp uncertainties ranging from 2.7% at 250 nm to 1.2% at 600 mm and 1.2% at 1600 nm.	A research effort is now devoted to extending the spectral range on the quartz halogen lamp to 2500 nm.
9. Calibration of detector spectral sensitivity in the range 200 to 400 nm with an uncertainty of 5%.	NBS presently provides calibrations in the range 250 to 960 nm with uncertainties ranging from 5% to 1% (see item 5 above).	Long-term research efforts may eventually extend the range to 200 nm.

SPECTROPHOTOMETRY

NBS Contact: Jack J. Hsia (301) 921-2791

Requirement	Current NBS Capability	Plans and Comments
1. Calibration of IR transmission filters at 10.0 μm.	None.	Measurement capability is presently being developed for the spectral range 2 to 25 μm with accuracies of 1 to 3% of measured value. Progress is dependent on continued availability of funding.
2. MAP program to calibrate, on-site, the photometric linearity of spectrophotometers.	Standard Reference Material 930 is a set of neutral density filters with transmittances of 10%, 20%, and 30% with an uncertainty of 0.5%.	A MAP program is being developed to cover the transmittance range 0.1% to 90% with uncertainties of 0.5% to 0.03%. This MAP program will be available in 1985.

RESPONSE TO SECTION 2E
TEMPERATURE, PRESSURE, AND RELATED MEASUREMENT SERVICES

TEMPERATURE MEASUREMENT

NBS Contact: Robert J. Soulen, Jr. (301) 921-3315

The major area for development in thermometry is a Measurement Assurance Program (MAP). The NBS presently has a MAP in the SPRT and Industrial PRT's, which cover the temperature range from 14 to 900 K. We wish to establish a MAP for the range 0.5 to 30 K (EPT-76) and such a MAP has been started by the calibration of sensors for several laboratories. Its maintenance will depend strongly on MAP funding for 1985. The region above 904 K is probably not ready for a MAP yet: issues are being raised as to whether thermometry would be best conducted using new PRT's, thermocouples or even an optical fiber thermometer. Until these issues are resolved (1 to 2 years) a MAP is probably not advisable.

Requirement	Current NBS Capability	Plans and Comments
1. 2 < T < 273 K; Cryogenic Range - Reproducible Triple Point Cells are required. Standards require ±1 mK reproducibility or better and will be used for calibration of thermometers.	Traceability exists with wire resistors (platinum and germanium) and superconducting fixed points (SRMs 767A and 768).	NBS has completed an evaluation of the triple point of Argon and is presently examining Oxygen. NBS also plans to evaluate the triple points of Neon, Nitrogen, and Deuterium. NBS is providing design information to commercial manufacturers and will conduct certifications of commercial units.
2. 272 < T < 473 K; Biological (Medical) Range require fixed point standards such as freezing point of gallium (29.77 °C), rubidium (37 °C), indium (156 °C), succinonitrile (Triple Point at 58 °C). Standards require ±1 mK reproducibility or better and will be used for calibration of thermometers.	Gallium (SRM 1968) and rubidium (SRM 1969) Standard Reference Materials are now available.	The Succinonitrile SRM is in production and should be available by late 1984. Indium SRM production will then follow.

(table continued)

	Requirement	Current NBS Capability	Plans and Comments
3.	273 < T < 1200 K; Covered by platinum resistor thermometers. Freezing point standards exist for primary points. Advantageous to develop secondary standards in order to cover smaller temperature intervals between fixed points and to serve as checks on calibration. Standards require ±1 mK reproducibility or better and will be used for calibration of thermometers.	The Region up to 904 K is well covered with 1 mK accuracies. Also thermocouple calibration accurate to ±0.1 K as prescribed by IPTS are provided in the range 904 to 1200 K.	NBS is evaluating special high temperature PRT's with the goal of ±0.01 K accuracy. Commercial resistors will be evaluated in 1984 and 1985. Recommended calibration scheme will depend on BIPM. NBS is also examining the feasibility of a new optical fiber probe thermometer with ±0.01 K accuracy from approximately 800 to 2000 K. Prototype will be evaluated in 1984. Possible calibration service in 1985.
4.	T > 1200 K; Higher accuracies in the calibrations and standards are required (Steel industry for thermocouples).	Thermocouple calibration services up to 2000 °C are available with accuracies better than 3 °C.	Development work for higher accuracy TC standards is being done.
5.	High Temperature PRT's	NBS is conducting studies of them.	Commercial development is underway. NBS will serve as evaluator of stability and reproducibility of commercial units.
6.	MAP; Reinitiate program for PRT's and extend to TC's as well as GRT's. Eventually even rhodium-iron thermometers should be added.	Resistance Thermometer MAPs are already available for PRT's. The procedure consists of sending PRT's from the NBS to MAP participants who measured the PRT's several times at several fixed points or other standards. Data is then analyzed by NBS.	NBS efforts in this area may be curtailed in the future due to reduction of MAP funding. An extended program for GRT, Rh-Fe, and TC's will require additional manpower.

(table continued)

Requirement	Current NBS Capability	Plans and Comments
7. Documentation	NBS has complete documentation on: PRT's; liquid-in-glass; thermocouples; gas thermometry; and medical thermometry covering the temperature range from 13 to 1200 K.	A new book emphasizing measurements in practical situations is in progress. Planned completion 1984. A Special Publication is planned for the EPT-76 scale which will cover temperature measurements down to 0.5 K. Planned completion 1984.
8. Automation	The prototype automation project for temperature measurement from 0.5 to 30 K has gone extremely well.	NBS will take the experience gained on the prototype system and apply it to other calibration services - a big job requiring new facilities. Plans are as follows: a. Automation of RhFe resistance and GERT resistance thermometers. Calibration service from 0.5 to 30 K is completed. Documentation of hardware and software will be completed in 1984. b. Automation of capsure PRT (13 to 373 K). This project requires new apparatus and could be completed by late 1985 if resources are available. c. Semi-automation of SPRT's is anticipated in 1985. d. Automation of thermocouple calibration service was completed in 1983. e. Automation of liquid-in-glass thermometry not feasible.
9. Instruction Material	NBS conducts two Precision Thermometry Seminars per year.	NBS will revise the material presented in the Seminar and develop new handout material in 1984. Videotape is an excellent instructional medium but the cost prohibits NBS from initiating a production project at this time.

PRESSURE MEASUREMENT

NBS Contact: Charles Tilford (301) 921-2121

The NCSL study indicates two areas in pressure measurements in need of improvement: (1) documentation and (2) improved accuracy in calibrations offered. The first area includes improvement of the calibration reports and development of NBS Special Publications which describe the service in great detail. Improved calibration reports are expected in 1984 and the NBS Special Publications will be completed in 1985 and 1986.

	Requirement	Current NBS Capability	Plans and Comments
1.	Calibration of gas piston gages for P < 600 psi.	Service available at 50 ppm accuracy level.	Calibration of 3 piston gages with high precision manometer has been completed. Results will be transferred to the calibration service at the 10 ppm accuracy level in 1984. Document describing improved calibration service will be completed in 1984.
2.	Calibration of gas piston gages for P > 600 psi	No calibration service offered.	NBS plans are: Develop primary piston gage standard by 1984 and offer calibration service at 30 ppm accuracy level in 1985. Documentation will be completed in 1985.
3.	Calibration of oil piston gages for pressures from 4000 to 40,000 psi.	Service available at 75 ppm accuracy level.	No improvement planned here. NBS now provides accuracies exceeding NCSL needs. The statement that "NBS can handle up to 1000 psi only at 0.01% level" is in error.

VACUUM AND LEAK MEASUREMENT

NBS Contact: Charles R. Tilford (301) 921-2121

We are in agreement with the three findings of the NCSL Report: (1) the pressure range down to 10^{-6} Torr is adequately covered by present NBS calibration services. (2) The region below 10^{-6} Torr is of considerable interest to many groups, but NBS has no present activity in this vacuum region, and (3) no NBS activity exists in leak standards despite considerable interest and activity in that region outside NBS.

The region down to 10^{-6} Torr is covered by new ion gage and spinning rotor gage calibration services. The planned activity here will be a continuing study of stability of these gages and factors which affect stability, reproducibility, and reliability.

For the pressure range below 10^{-6} Torr, NBS plans are as follows. Any progress made will be an offshoot of the leak program described below. Since the funding of the program by an outside agency is specifically for leak standards, the emphasis will be on leaks. Pressure measurement is an auxiliary part of the leak program, however, so we hope to make some progress in vacuum measurements below 10^{-6} Torr.

NBS has received support from an outside agency to begin a leak program in 1984 and extending for four years, thereafter. Some support has also come from an internal NBS program. The support will be for one professional staff member and a half-time technician per year. The program goals and deadlines are given below.

Requirement	Current NBS Capability	Plans and Comments
1. Calibration of ion gages in the range 10^{-3} to 10^{-6} Torr with an uncertainty of 5%.	Service is available.	NBS standards are being tested to extend calibration range to 10^{-1} Torr and reduce uncertainty to 1 to 2%.
2. Calibration of spinning rotor gages in the range 10^{-3} to 10^{-6} Torr to 5%.	Service is available.	NBS continues to study systematics; to extend calibration range to 10^{-1} Torr; and to reduce uncertainty to 1-2%.
3. Calibration of any device below 10^{-6} Torr.	None.	Depending on leak program, some standards in pressure below 10^{-6} Torr may become available in 1986.

(table continued)

Requirement	Current NBS Capability	Plans and Comments
4. Calibration of leak standards in the range 10^{-3} to 10^{-8} std cc/sec with an uncertainty of 5%.	None.	Research program initiated in 1984 (1.5 MY). Expect development of primary leak standard and calibration service in 1987.

LIQUID AND GAS FLOW MEASUREMENT
NBS Contact: James R. Whetstone (301) 921-3681

The ten respondents to this portion of the survey are only a small fraction of the current community served by the NBS calibration services in this area. Largely, the information in the report is consistent with feedback from the customer community. The responses indicate that NBS is responding to the customer's needs and that plans in place for improvement of the currently offered services meet their future needs, with the exception of a need for a capability in steam flow measurement. We have no current plans for development of a service in this area.

Judging from the Report, the members of the requirements committee and the respondents primarily deal with single phase fluids. In our discussions with industry there is a major need for flow measurement capability in the area of multiphase flows, solid-fluid flows in particular. There have been extensive reports by the American Institute of Physics and American Society of Mechanical Engineers citing the need for accurate measurements and metering of solid-fluid flows. We are now initiating projects to attack the problems of making accurate solid-fluid flow measurements.

Presently the Center for Chemical Engineering plans to maintain the currently offered calibration services for gas and liquid flows. The current emphasis is placed upon upgrading the uncertainty statements for each facility and automating them to decrease turnaround time. A substantial fraction of the effort in the Flow Metrology Group of the Chemical Process Metrology Division is directed toward the development of expertise and a facility for the measurement of flow parameters for solid-liquid flows. When development of this expertise and the solid-liquid flow facilities is complete, new calibration services will be offered in this area and will be unique in the U.S.

LIQUID AND GAS FLOW MEASUREMENTS
NBS Contact: James R. Whetstone (301) 921-3681

Requirement	Current NBS Capability	Plans and Comments
1. MAPS	Laboratory intercomparisons for flow measurements have been arranged by NBS, although a formal MAP service is not available.	Similar intercomparisons for gas flow will be initiated when a sufficient number of participants is found.
2. Documentation	Documentation is available concerning the physical properties of gases vital to flowmetering.	Additional efforts in providing documentation are underway and will continue.

(table continued)

Requirement	Current NBS Capability	Plans and Comments
3. Liquid flow accuracy of 0.05% at rates of up to 110 GPM.	Present liquid flow accuracy is 0.1%.	Current plans and efforts are aimed at upgrading the facility using new methods for all parameter measurements that are more directly tied to the base units so that facilities can be automated. In doing so the accuracy of the facilities may approach 0.05%. The primary objectives are to decrease the turnaround time and cost of the calibration services and improved ties to the base units of measurement.
4. Gas flow for rates of 1 to 50,000 SCIM at ±0.1% i.v.	Present gas flow accuracy is ±0.2% i.v.	Current plans are aimed at improving the accuracy to ±0.1% i.v.
5. Steam flow	None.	There are currently no plans to develop in-house facility for steam flows.

THERMAL CONDUCTIVITY/CONDUCTANCE STANDARDS
NBS Contact: Jerome G. Hust (303) 497-3733

The NCSL Report indicates the need for a much wider range of SRMs including both a wider range of temperatures and of thermal conductivities. Within the funds available, NBS is attacking the highest priority needs.

NBS' Center for Chemical Engineering (CCE) provides measurement services of interest to the chemical process industries. The small but continuing effort of CCE is directed towards satisfying needs of the kind identified by the NCSL Report. The most critical needs of industry at present are:

a) A low conductivity solid SRM with a range of conductivity comparable to geologic, plastic, composite, or agggregate materials.

b) A low conductivity insulation SRM for use above ambient temperatures.

The high cost of production may prohibit the preparation of the low conductivity solid but work has started on the insulation material. A glass-fiber board (SRM 1450) is available for use at ambient temperatures.

ELECTROLYTIC CONDUCTIVITY
NBS Contact: William F. Koch (301) 921-2883

We fully agree with the Report that electrolytic conductivity is an area in which there are real needs for high-accuracy standards and traceability to NBS over the full range of 10^{-6} to 1 siemens/cm. These measurements are important in the pharmaceutical and power industries as well as for oceanographic studies, environmental issues (acid rain, water quality, etc.), and fundamental studies in the theory of electrolytes. These measurements have implications in health related areas, such as the effect of electric fields on living cells and tissue.

NBS is currently funding a project to study the feasibility of providing aqueous conductance standards as SRMs. This is essentially a start-up effort to explore needs and capabilities, after years of inactivity in this field of research at NBS. The needs of the scientific and industrial community will best be met through NBS participation and research, and through the issuance of a set of SRMs for electrolytic conductance.

RESPONSE TO SECTION 2F
PHYSICAL/MECHANICAL MEASUREMENT REQUIREMENTS

The material included in this section of NBS' Response is supplemental to that already included in the NCSL Report.

SHOCK MEASUREMENT

NBS Contact: Myroslav R. Serbyn (301) 921-3607

The NCSL Report confirms our conclusion that there is a need for a shock calibration service to fill the void left when the former NBS shock calibration service was terminated in 1975. We are in the process of reestablishing the shock calibration facility. Our shock-test machine has been factory overhauled during the past year and space for its installation has been obtained. It is expected that it will be installed and operating before the end of this year. Initially the service provided will be on a comparison basis, but if funds permit, this will ultimately be upgraded to an absolute service.

Requirement	Current NBS Capability	Plans and Comments
Calibration of shock accelerometers using comparison methods to 30,000 g's with an certainty of 1% to 5% and to 10,000 g's with an uncertainty of 5% to 10%.	None	Calibration services for shock accelerometers, using comparison methods, from 50 to 3000 g's with an uncertainty of 5% is expected to be available in one year.

HUMIDITY (HYGROMETRY) STANDARDS

NBS Contact: Saburo Hasegawa (301) 921-2794

No new requirements were identified, but one respondent requested that existing services be continued. Our present services for humidity measurement devices are being automated to improve turnaround time.

PARTICLE SIZE STANDARDS

NBS Contact: Lee J. Kieffer (301) 921-2536

The NCSL Report confirms our conclusions that there is a need for particle-size Standard Reference Materials. The NBS Office of Standard Reference Materials has two new particle SRMs (0.3-μm and 0.9-μm spheres) that are available and will soon start work on 3-μm and 10-μm spheres.

Requirement	Current NBS Capability	Plans and Comments
Spherical particle SRMs having 0.5 to 1.0 μm diameters with uncertainty of 5%.	SRMs now available for spherical particles of nominal diameter of 0.3 and 0.9 μm with uncertainty of 1%.	Plans are to prepare a series of polystyrene spheres having diameters of 0.1, 0.3, 0.9, 3, 10, and 30 μm.

LIQUID DENSITY (HYDROMETRY) MEASUREMENTS
NBS Contact: James R. Whetstone (301) 921-3681

No new requirements were identified, but one respondent requested that existing services be continued. NBS plans to maintain the currently offered calibration services for hydrometers. To support new technology in the measurement of liquid density, Standard Reference Materials are planned. These will provide a direct tie to the unit of density as embodied in the single-crystal silicon density standards maintained by NBS.

DIMENSIONAL MEASUREMENT
NBS Contact: James R. Shaver (301) 921-2983

Our goal is to structure the Dimensional Metrology Program to handle the broad range of industrial needs, both now and in the long term. Specifically, we plan to maintain calibration services for manual artifacts such as gage blocks, spheres, and cylindrical standards. We also plan to maintain our support to the gaging community through the calibration of thread gages, plug gages, etc.

Our long term plan is to gradually reduce the number of such calibrations, allowing them to be done by secondary laboratories. Our current priority with respect to coordinate measuring machines is towards the adoption of the B89.1.12 Interim Standard as a National Standard, thus providing a traceability chain to NBS through the use of laser wavelengths or simple calibrated artifact standards such as step gages. In this way we seek to avoid calibrating large numbers of large, heavy, difficult to maneuver gages such as ball and hole plates. We intend to continue to offer one-of-a-kind special tests for these artifact standards should they be required by a particular organization.

The major priority of our program is to develop the new technology which we believe will be necessary for metrology in the factory of the future. That is, metrology techniques that control the dimensions of the part during the time it is being manufactured. We call this approach "Deterministic Metrology", and the major thrust of the program is the characterization of machine tools, tooling, thermal and other errors that lead to incorrect parts, and sensors for monitoring such errors. This approach involves ensuring that quality assurance is built into the manufacturing process rather than focussed on inspection after the part is manufactured.

The only specific comment in the NCSL Report that dealt with Dimensional Metrology concerned coordinate measuring machines. We do have an extensive program in coordinate measuring machines, and we will continue to support the development of this technology and the dissemination of information to users. Through the Office of Standard Reference Materials we have made available a socketed-ball-bar set (SRM 2083) which can be used to determine the performance of a coordinate measuring machine in accordance with ASME Standard B89.1.12. We will also continue to develop the software supplied with such machines, including the computational algorithms for acquiring metrology information. We believe in the long run that the standardization of such algorithms will lead to more accurate measurements.

HARDNESS STANDARDS
NBS Contact: David Lashmore (301) 921-2958

NBS has conducted a research project on the development of diamond pyramid hardness standards and now currently offers two SRMs through the Office of Standard Reference Materials. These are in the nominal ranges of 125 KHM (SRM 1894) and 550 KHM (SRM 1895) and will be certified both for Vickers and Knoop hardness at three commonly used loads of 25, 50 and 100 gf. The accuracy of the SRMs are certified at ±5% and information is supplied to the purchaser to allow use at other loads.

Presently research is underway to develop additional diamond pyramid hardness standards at ranges of 60 KHM, 800 KHM, and 1200 KHM. All of these standards have had all of the individual components which are involved with their certification calibrated against NBS fundamental standards of mass and length. Their surface finish is standardized and the measurements carried out in accordance with the appropriate ASTM recommended practice.

The need of industry for uniform diamond pyramid hardness standards has been widely known and documented. However, it remains unclear the extent to which industry requires NBS certified Rockwell standards. If Rockwell standards were necessary, electroforming techniques similar to those currently used with the diamond hardness SRMs could be used to fabricate the Rockwell standards, however, cast alloys may be more economical and serve just as well. This processing technology results in an extremely uniform material.

AUTOCOLLIMATOR MEASUREMENT
NBS Contact: William Gallagher (301) 921-2216

One respondent requested the calibration of an autocollimator with 10 minute nominal range and 0.1 sec and of arc accuracy. While turnaround times for this service are longer than we would like, this service is readily available from NBS.

EDUCATIONAL SEMINARS AND WORKSHOPS
NBS Contact: R. Keith Kirby (301) 921-2805

REQUIREMENT:

The NCSL national measurements requirements survey states: "One of the requirements common to most of the data packages and common to most of the respondent laboratories is the need for educational seminars and workshops along with technical information. There is a continuing need for these extremely important services in order to maintain well qualified and knowledgeable personnel in our laboratories. There is no more authoritative source for personnel working with primary standards to obtain this type of training and information than through the NBS."

NBS SEMINARS AND WORKSHOPS

SEMINAR ON DIGITAL METHODS IN WAVEFORM METROLOGY
October, 1983 at NBS Gaithersburg
Contact: Barry A. Bell (301) 921-2727

This two-day seminar on Digital Methods in Waveform Metrology incorporated a program of lectures and laboratory demonstrations by NBS staff and discussion sessions. The seminar was intended to familiarize technicians, engineers, and scientists with the fundamental principles relating to precision waveform metrology in the dc-to-10 MHz regime, and to acquaint the attendees with the specific metrology program being carried out at NBS. The program was divided into presentations on precision waveform synthesis (digital waveform synthesis techniques, phase angle standards and calibration methods); precision waveform sampling (characterization of waveform recorders, dual-channel sampling systems); data converter characterization (static/dynamic data converter testing, settling-time measurements); and instrumentation metrology (automatic thermal voltage converter calibrations, conductance measurements of gallium arsenide switches, automatic test equipment performance measurements and standards, conducted EMI effects on test equipment). Future similar seminars are planned.

WORKSHOP ON LASER BEAM PROFILE MEASUREMENTS
March 20, 1984 at NBS Boulder
Contact: Eric G. Johnson (303) 497-3234

This one day workshop will be held to identify problems in laser beam profile measurements, to discuss what NBS can do to help solve these problems, and the decide on the future role of NBS.

PRECISION THERMOMETRY SEMINAR
March 19-23 and October 15-19, 1984 at NBS Gaithersburg
Contact: Robert J. Soulen (301) 921-3316

This seminar will consist of integrated instruction in Platinum Resistance Thermometry, Liquid-in-Glass Thermometry, Thermocouple Thermometry, and Thermistor Thermometry to be given over a five day period. Material to be covered includes the International Practical Temperature Scale of 1968; its use in the laboratory; thermometers and instrumentation, including automatic

data acquisition; the treatment of calibration data; and innovations in thermometry. Time will be split between lecture sessions and hands-on measurements in the laboratory. The seminar is especially intended for calibration laboratory personnel and others who wish to undertake precision temperature measurements.

SEMINAR ON ELECTRICAL MEASUREMENT ASSURANCE PROGRAMS
March 26-30, 1984 in Dallas
Contact: Arthur O. McCoubrey (301) 921-3301

This five-day intensive seminar on measurement quality assurance provides in-depth training for those involved in dc and low frequency electrical measurements. Participants will receive instruction on how to establish and maintain rigorous quality control programs in their own laboratories to ensure the accuracy of electrical measurements. The primary emphasis will be on quality control for dc voltage metrology; the techniques used are readily applicable to other electrical measurement areas.

SEMINAR ON ELECTROMAGNETIC NOISE MEASUREMENT
April 30-May 4, 1984 at NBS Boulder
Contact: Ramon C. Baird (303) 497-3301

This seminar is intended for practicing noise metrologists and technical managers responsible for antenna and communication systems where accurate noise measurements are important. Sessions will address the accurate measurement of noise power, amplifier noise, and antenna system noise such as noise equivalent flux and G/T. Practical and theoretical aspects of precision noise measurement will be presented.

CALIBRATION AND USE OF CONTROLLED-CLEARANCE PISTON GAGES
April 2-6, 1984 at NBS Gaithersburg
Contact: Joanne Packard (301) 921-2121

This course will cover the theoretical and practical aspects of the calibration and use of controlled-clearance piston gages. Particular emphasis will be placed on the 100,000 psi Harwood gage. It will include lecture seminars, laboratory demonstrations, and hands-on experience. Emphasis will be placed on the acquisition and analysis of data required for the characterization of the gage as a primary standard. Attendance will be limited and participants will be split into smaller groups to facilitate use of the equipment and opportunities for individual questions.

The agenda will include:

Theory of controlled-clearance gas
Acquisition of fall-rate data
Crossfloating to determine effect of jacket pressure on area
Analysis of laboratory data
Error estimation

SEMINAR ON FREQUENCY MEASUREMENTS AND CALIBRATION
April, 1984 at NBS Boulder
Contact: Mike Lombardi (303) 497-3212

This seminar is intended for engineers and standards lab technicians involved in frequency calibrations. The course will be taught at a practical level to satisfy those new to the field as well as more experienced users. Methods taught will use commercially-available equipment. Topics to be covered:

Crystal Oscillator Calibration
Applications of Frequency Counters
How to Choose a Frequency Calibration
Care and Use of Frequency Sources
Using Loran-C and WWBV for Frequency Calibrations
Time and Frequency Measurement Assurance Services at NBS
Organization of Time & Frequency in the U.S.
NBS, USNO, and Other Publications

SEMINAR ON QUALITY ASSURANCE OF CHEMICAL MEASUREMENTS
May 2-3 and 9-10, 1984 at NBS Gaithersburg
Contact: John K. Taylor (301) 921-3497

This two-day seminar is concerned with techniques to improve the precision and accuracy of analytical measurements such as those needed in the compositional analysis of materials, process control, and regulatory enforcement. It is designed for supervisors of analytical laboratories, experienced analytical chemists, and those responsible for the development and/or supervision of laboratory quality control programs. Topics discussed will include: general aspects of quality assurance; the role of Standard Reference Materials in quality assurance; statistical considerations used in the evaluation of data quality; good laboratory practices for precise and accurate chemical measurements.

SEMINAR ON THE CALIBRATION AND USE OF PISTON GAGES
May 17-18 and November 15-16, 1984 at NBS Gaithersburg
Contact: Bernard E. Welch (301) 921-2121

This seminar is held to help industrial and other users attain the highest possible accuracy in pressure measurements with piston gages. The seminar is directed at engineers and senior technicians. The two-day seminar presents information on the theory of piston gages, elastic distortion, design and types, calibration of controlled clearance piston gages, calibration by cross-float, error analysis, computer programs, demonstration of cross-float, hydrostatic weighing and transducer calibrations.

SEMINAR ON FREQUENCY STANDARDS AND CLOCKS
August, 1984 at NBS Boulder
Contact: Mike Lombardi (303) 497-3212

This seminar is intended for program managers, planners, and systems engineers. Topics to be covered:

A History of Time Scales
National and International Structure of Time & Frequency
Concepts, Definitions, and Measures of Short-Term Frequency Stability
Techniques for Measuring Short-Term Frequency Stability and Noise in Oscillators
Review of Performance of Commercial Frequency Standards
Limitations of Present-Day Atomic Frequency Standards
Possible Advances in Future Clocks and Frequency Standards
The Process of Timekeeping (Clocks Modeling)
Time Coordination: Methods for Comparison of Time Scales
Propagation Effects on Radio Transmissions
Optical Techniques and Propagation Effects

SYMPOSIUM ON OPTICAL FIBER MEASUREMENTS
October 2-3, 1984 at NBS Boulder
Contact: Douglas L. Franzen (303) 497-3346

This symposium will provide a forum for reporting the results of current research and an opportunity for discussion that can lead to further progress on experimental or analytical aspects of the characterization of optical fibers and fiber optics systems, including attenuation, bandwidth/distortion, dispersion, index profile, cut-off wavelength, mode diameter/core geometry, fiber device (e.g., joint, coupler, multiplexer, etc.) evaluation, physical measurements, link parameters (e.g., concatenation), polarization characteristics, system performance, field measurements, and standards.

WORKSHOP ON MEASUREMENT OF GAGE BLOCKS
Held every few years at NBS Gaithersburg
Contact: Theodore D. Doiron (301) 921-2216

There are no current regularly scheduled training programs in gage block metrology, however every few years on customer demand a one-week workshop is offered. Those interested in participating in such a workshop should contact the Dimensional Metrology Group.

LINEWIDTH TRAINING SEMINAR
This seminar has been held about twice a year at various locations
Contact: Diana Nyyssonen (301) 921-3786

This seminar is primarily intended to transfer NBS linewidth measurement technology to users in industry. Participants receive instruction in the basic workings of the optical microscope and the NBS-recommended linewidth measurement procedures.

Lectures, discussion, and equipment demonstrations cover state-of-the-art theory of optical measurement equipment and edge detection for linewidths in the 0.5- to 10-micrometer range. Specifically treated are procedures for setting up and calibrating equipment and analysis of calibration data with emphasis on establishment of precision and uncertainty. Lectures and discussion also include problems associated with linewidth measurements made with the scanning electron microscope (SEM) and other electron-beam systems.

NBS/ASTM SYMPOSIUM ON RADIATION THERMOMETRY
May 8, 1984 at NBS Gaithersburg
Contact: Kenneth G. Kreider (301) 921-3281

This symposium is sponsored by NBS and ASTM Committee E20, Temperature Measurement. Technical papers will be presented on principles of measurement, methods of calibration, industrial applications, and case studies and recent research developments, including optical fiber thermometry and gas temperature measurements in combustion systems.

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This response of the National Bureau of Standards (NBS) to the 1982 National Measurement Requirements Survey Report published by the NCSL's National Measurement Requirements Committee in May 1983 contains detailed information on the measurement services presently available from NBS and our future plans for new and expanded services. The information contained in the Survey Report is extremely useful to NBS in evaluating the effectiveness of ongoing programs and for planning future programs. The Report is particularly important to NBS because of the large number of organizations that have responded and because of the detailed technical requirements identified in the report.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Calibrations, NBS measurement services, standard reference materials

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